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MECHANISMS OF EXCITING PRESSURE OSCILLATIONS IN RAMJET
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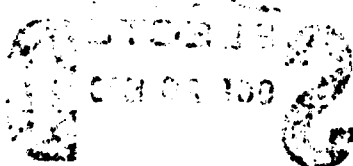
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modeling of the steady flow field. Special attention is being directed to unsteady shear layers and combustion in a vortex as a mechanism for exciting pressure oscillations. Utilizing the physical model derived from the transient burning of a flame in a vortex field, it has been possible to correlate screech data for a wide variety of fuels.

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I. RESEARCH OBJECTIVES

This report covers the first year of a program concerned with the mechanisms for low frequency pressure oscillations in ramjet engines. Both analytical and experimental work is included. The analysis covers both detailed examination of specific mechanisms and the acoustical framework within which the relative influences of various mechanisms may be assessed. The experimental work is initially being performed in a small scale laboratory dump combustor. Subsequent tests related to the problem of scaling will be carried out in a larger facility at the Air Force Aero Propulsion Laboratory.

A. Analytical Work

1. Modelling the Steady Flow Field in a Dump Combustor

As part of the basis for carrying out analysis of the unsteady motions, it is necessary to have a model of the steady flow field. The purposes of the present program, items 2 and 3 below, will be adequately served by a relatively crude approximation to the actual field. We intend to assume that combustion occurs in a flame sheet anchored at the dump plane. Ignition of the incoming flow is sustained by hot gases supplied from the recirculation zone which is separated from the main part of the chamber by a shear layer. We shall approximate the shear layer as an infinitesimally thin discontinuity of velocity. To the greatest extent possible, integral methods will be used to formulate approximate solutions for the various regions of the chamber. Errors in the representation of the steady flow field can be tolerated because the results will appear only as parts of integrals in the analysis of the acoustic field.

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Chief, Technical Information Division

2. Analysis of the Linear Acoustic Field

The description of the acoustic field will be constructed in the manner used to analyze corresponding problems in liquid and solid rockets. Modifications will be required to accommodate the strong gradients of the average temperature and velocity fields. Moreover, account must be taken of the inlet shock system and the high speed flow in the inlet.

3. Analysis of Nonlinear Acoustics

Approximate techniques, developed and used for studying pressure oscillations in solid propellant rockets, will be used to analyze nonlinear behavior in ramjet engines. The ultimate purpose is to understand the processes responsible for limiting the amplitudes of steady oscillations.

4. Comparison With Data

Results of the analyses will be used to correlate and interpret data. In addition to data acquired in the present program, we shall be supplied with observations and measurements taken with a laboratory combustor operated at the Naval Weapons Center, China Lake.

5. Vortex Combustion in a Flame Sheet

A guiding hypothesis in this program is that unstable shear layers and vortex shedding are likely to be primary causes of instabilities in ramjet engines. Hence much attention will be paid to combustion in vortices. The growth and reactant consumption rate of flames distorted by the flow field of a vortex will be calculated utilizing the approximation of local flame structure

along the flame sheet. The result of this study will be the characterization of the combustion pulse and the time of its occurrence after formation of the vortex. Included will be the scaling laws for the combustion pulse magnitude and time delay for various chemical and gasdynamic situations. Utilizing these results, the acoustic response to the non-steady combustion will be analyzed.

6. Vortex Combustion with a Distributed Flame

A distributed flame model, in contrast to the flame sheet model, will be developed in an effort to obtain a realistic description of the non-steady flame zone which may be extended to large-amplitude, non-linear situations.

B. Experimental

The general objectives of the experimental program are to acquire data concerning unstable combustion in a dump burner which can be used to verify and correct the theoretical analyses. In addition, we aim to carry out large scale tests in cooperation with AFAPL to verify the scaling procedures developed in the small scale tests.

During the first year our objectives were to develop the existing burner so that tests with choked exhaust nozzles could be tested in the dump and bluff body flame holder modes. Instrumentation and data reduction software will be developed.

II. STATUS OF RESEARCH

A. Analytical Work

1. Modelling the Steady Flow Field in a Dump Combustor

Most of the effort during the first year has been devoted to construction of equations matching conditions and development of integral methods. The representation of the steady flow field is not complete, the primary difficulty being a satisfactory description of the flow in the recirculation zone.

2. Analysis of the Linear Acoustics Field

An analysis of the inlet shock, begun under a previous program elsewhere, has been completed. This has been used as the upstream boundary condition for some preliminary calculations of the acoustics field without combustion and average flow accounted for in the combustion chamber. Comparison with limited data provided by the Naval Weapons Center, China Lake shows fairly good agreement in some respects. It is not clear to what extent the differences are due to ignoring combustion and flow in the combustion chamber.

3. Analysis of Nonlinear Acoustics

During the first year, work has started on the problem of the conditions for existence and stability of limit cycles. No substantive results have been obtained to date.

4. Comparison with Data

This work has not been started during the first year.

5. Vortex Shedding and High Frequency Instabilities

Conventional afterburners on ramjet configurations, which incorporate v-gutter flame stabilizers, frequently exhibit a high-frequency instability where the acoustic wave-length of significance is of the order of the distance separating flame-holder rings. We have identified the mechanism of this instability from extensive,

detailed observation. Suppose there is a transverse acoustic oscillation in the plane of the flame holder; when the acoustic velocity is vertically upwards, a vortex is shed from the lower lip of the flame holder. It is transported downstream, grows, and entrains combustible gas which it mixes with hot combustion products from the flame holder wake. After a delay time, determined by the rates of chemical reaction in the combustion process, the vortex burns. This concentrated and rapid combustion constitutes an acoustic pressure source; if the characteristic chemical time permits pressure pulse to be emitted in the proper phase of the acoustic oscillation, the acoustic mode will be amplified and the combustion process is unstable.

The detailed analysis of combustion in such vortex structures forms a portion of the work under this grant. To date, much of our work on this problem has treated diffusion flames deformed by vortex structures. However the ideas and methods of analysis developed there may be carried over almost directly to the pre-mixed flows.

The problem treated is the behavior of this flame when, at some time, a vortex is situated at the flame front separating burned from unburned gas. During the ensuing motion the flame surface area is enhanced enormously, the rate at which it is strained leading at first to a decrease in combustion rate, later to a considerable increase. The result is a combustion or heat-release pulse which takes place a certain time after the vortex is formed; the heat release pulse occurs at a time of the order of τ_c , where τ_c is the

chemical time which occurs in the formulation of the reactant consumption rate of a pre-mixed gaseous flame

$$m = \rho \frac{k}{c_p \rho} \frac{1}{\sqrt{\tau_c}}$$

in which k , c_p and ρ are the thermal conductivity, specific heat and density of the gas mixture. The amplitude of the heat pulse, on the other hand, scales as $\rho \Gamma^{2/3} \frac{k}{c_p \rho} \frac{1}{\sqrt{\tau_c}}^{1/3}$, where Γ is the circulation of the vortex generated at the flame holder lip.

For the mechanism we have discussed to lead to instability, the time delay after formation of the vortex, must be approximately equal to the period of the oscillation, that is approximately equal to τ_c .

One of the experimental characteristics of such an oscillation that can be measured with considerable accuracy is the lean screech limit. This is the mixture ratio at which this mode of instability first appears as the mixture ratio is increased, the gas velocity and other properties of the flow remaining constant. We have shown that the physical reason for this phenomenon is, that as the mixture ratio is increased on the lean side, the characteristic time, $\sim \tau_c$, is decreased and eventually this pulse occurs at the proper phase to energize the oscillation. Thus the measurement is not only a sensitive one, but it is an equally sensitive check on our model of vortex combustion time delay. Using our vortex combustion model, we are able to correlate the lean screech limit for various conditions with remarkable accuracy. This has been particularly impressive when we obtained lean screech limits on the same piece of hardware for

seven different fuels. (Actually, they were seven different mixtures of hydrocarbon fuel with hydrogen.) Although, these fuels had effective chemical time constants that differed by a factor of nearly 100, (leading to a flame speed variation of a factor of 10) we were able to correlate the lean screech limits within 5%. We feel, therefore, that we are obtaining a firm grip on some of the basic phenomena that will be of direct utilization to the Air Force.

III. PUBLICATIONS

Culick, F. E. C., and Rogers, T., "The Response of Normal Shocks in an Inlet Diffuser," AIAA/ASME/SAE 17th Joint Propulsion Specialists Meeting (July 1981) AIAA Preprint No. 81-1431

(Note: This was initiated in 1980 as a joint effort with the Marquardt Company and completed under the present program.)

IV. PERSONNEL

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IV. INTERACTIONS

- (i) Paper delivered at 17th Joint Propulsion Specialists Meeting.
- (ii) Information exchange with personnel at the Naval Weapons Center, China Lake.

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